> "that the application disclosure does not contain sufficient evidence and reasoning to permit a person of ordinary skill in the art to believe that the asserted utility or that the process disclosed could achieve the asserted useful result, since Applicant has shown no evidence of reducing the speculation and conjecture to practice in either a laboratory or natural environment setting. Applicant has not presented any evidence to support the assertion of a credible utility, only speculation and conjecture."

By coincidence, an extensive article appeared in the October 2004 issue of the prestigious monthly "Scientific American", titled "Controlling Hurricanes" (pages 69 – 75), which, it is believed, provides such evidence to support the assertion of credible utility in Applicant's method and apparatus, and to show that Applicant's method and apparatus are not based on mere speculation or conjecture.

A copy of this article is enclosed and will be discussed below.

First, however, Applicant would like to discuss the objection and rejection, presented for the first time in the Final Action of October 6, 2004, on the grounds of "new matter", and then the rejections of the claims under 35 USC 101 and 112 repeated in the Final Action.

<u>The Objection and Rejection Based on "New Matter"</u>

This objection to the specification, and rejection of Claims 1 – 10, presented for the first time in the Final Action of October 6, 2004, is based on the holding that the language "a sea vehicle having capability of cooling water on a large scale", introduced in that amendment, constitutes "new matter" since it is not supported by the original disclosure. Favorable reconsideration of this holding is respectfully requested.

The present invention is based on the concept of inhibiting or weakening the formation of hurricanes by "cooling the surface water in an open water region immediately upon the detection of the onset of a hurricane in such a region" (page 5, lines 8 – 10). The subsequent passages in the specification further state (page 5,

lines 11 – 14) "The use of submarines, particularly nuclear-powered submarines, which are presently not operational offers a practical way of cooling the surface water in the open water region immediately upon the detection of the onset of a hurricane in such region."

Fig. 1 illustrates such a submarine including a water pump and conduits for pumping the cooler water at a depth below the surface of the open water region to the surface of the open water region for cooling the surface water in the open water region. Figs. 2 and 3 illustrate the use of a plurality of submarines for this purpose. Further described in the specification is the option that the submarine or submarines could include refrigeration units for further cooling the so-pumped water (page 6, lines 4 – 6).

Clearly, a "submarine" is a "sea vehicle". Also, clearly, such a submarine or submarines as described in the original specification have the "capability of cooling water on a large scale". Accordingly, while the amendment made to the specification and claims objected to by the Examiner under 35 USC 132 and 35 USC 112, first paragraph respectively, may be "new language", it certainly does not constitute "new matter" not supported by the original disclosure.

<u>The Rejection under 35 USC 101</u>

The rejection under 35 USC 101, as set forth in Sections 3 and 4 of the Final Action of October 6, 2004 is based on the holding by the Examiner that the

> "disclosed invention is wholly inoperative and therefore lacking in credible utility ".

In support of this holding the Examiner states:

> "What has been disclosed is a concept more in the realm of speculation and conjecture than the reduction of an idea to a practical application based on science and technology."

In further support of this rejection, the Examiner quoted a passage from the U.S. Supreme Court Decision Brenner v Manson, 148 USPQ 689, 696 (US SupCt 1966).

The above Supreme Court Decision has been studied, but the facts in that case are completely different from the facts in the present case. That decision involved the patentability of a chemical process for producing a known chemical compound. However, the utility of such a chemical compound had not been established, except for the fact that the compound belonged to a class of compounds which scientists were screening for possible use. Clearly, a new chemical compound is not patentable under 35 USC 101 until there is a showing of some utility for the compound. The Brenner decision held that the requirement for utility under 35 USC 101 was not satisfied by a showing that the produced compound belonged to a class of compounds which scientists were then screening for possible use (pp. 532, 536).

The present invention, on the other hand, is directed to a method and apparatus for inhibiting or weakening the formation of hurricanes. As well known, particularly by those residing in areas susceptible to hurricanes (which is the case with the present Applicant who resides in Long Key, Florida), hurricanes cause immeasurable property damage and loss of lives. For example, the following is a quotation from the Encyclopedia Britannica, volume 16, page 521;

> "Hurricanes can cause widespread destruction and human misery. An average hurricane has tremendous energy. In one day the energy released is about 1.6 x 10^{13} kilowatt-hours, or at least 8,000 times more than the electrical power generated each day in the United States. This quantity is equivalent to a daily explosion of 500,000 atomic bombs of 20-kiloton Nagasaki variety. These numbers should make it clear that it

> would be impractical to attempt to modify hurricanes by a brute force approach. It is necessary to find a means whereby a small input of energy may upset a natural instability and lead to large results. Ice-nuclei seeding is the one such approach now under investigation"

It is hard to conceive of any development that would have more utility than a method and apparatus for inhibiting, or at least weakening, the formation of hurricanes, which is the object of the present invention.

As will be more particularly discussed below, the present invention proposes another means, namely a "spoiler system" consistent with recognized understandings of physical phenomena, whereby a relatively small input of energy upsets or "spoils" a natural instability and leads to large results, namely the inhibition, or <u>at least the weakening</u>, of the formation of a hurricane. The amount of additional energy needed (i.e., the amount of cooling of the surface water that would be required) to effectively inhibit, or <u>at least weaken</u>, the formation of a hurricane, would depend to a large extent on how early the onset of the hurricane is detected, in the same manner that a forest fire can be inhibited or weakened by a relatively small input of energy if the fire is detected early.

As will be shown more particularly below, and as supported by the "Controlling Hurricanes" article attached hereto, it is believed that the basic operations of the novel method are capable of practical application in today's state of science and technology, and are not merely in the realm of speculation and conjecture as indicated by the Examiner.

Thus, Claim 1 defines the broad novel concept of the present invention, namely, a method of inhibiting <u>or weakening</u> (emphasis added) the formation of hurricanes, comprising the operations of (a) detecting the onset of a hurricane in a region of open water; (b) immediately moving to said region a sea vehicle having a capability

of cooling water on a large scale; and (c) immediately utilizing said vehicle for cooling the surface water in the open water region.

The Inventor, who is a retired physician and presently lives in Long Key, Florida where he has personally experienced hurricanes, is well aware of the devastation caused by hurricanes. He prepared material discussing the present state of the art applicable to both the possibility of detecting the onset of a hurricane, and the possibility of immediately cooling the surface water in order to inhibit, or at least weaken, the formation of the hurricane. A copy of this material prepared by the Inventor, together with a copy of each of the references cited therein, was included as an Attachment to the amendment filed March 4, 2004.

It is believed that this Attachment, the references cited therein, and particularly the attached copy of the "Controlling Hurricanes" article to be further discussed below, clearly show that the operations defined in method Claim 1 are capable of being achieved in the present state of the art and do not violate any recognized understandings of the physical phenomena involved.

It is submitted, therefore, that method Claims 1 – 10 define patentable subject matter under 35 USC 101.

Claims 11 – 16, drawn to the apparatus, are also submitted to define patentably subject matter under 35 USC 101 since such apparatus can be used for other purposes, for example the many purposes described in Girden U.S. Patent 3,683,627 and Bronicki, et al U.S. Patent 4,470,544, cited by the Examiner.

The Rejection under 35 USC 112, first paragraph

35 USC 112, first paragraph, relates to the completeness of the description of the invention, and requires that the description be sufficient "to enable any person skilled in the art to which it pertains, or with which it is most nearly connected, to

make and use the same and shall set forth the best mode contemplated by the Inventor of carrying out his invention".

It is submitted that the description in the present application is sufficient to meet the "enabling" requirement, as well as the "best mode" requirement, of 35 USC 112, first paragraph.

Thus, the specification describes, not only the main novel concept of the present invention, but also several specific implementations of the novel concept.

As indicated above, the main novel concept of the invention as defined, e.g., in Claim 1 is to inhibit, or <u>at least weaken</u>, the formation of hurricanes by the following operations: (a) detecting the onset of a hurricane in a region of open water; (b) immediately moving to said region a sea vehicle having a capability of cooling water on a large scale; and (c) immediately utilizing the vehicle for cooling the surface water in the open water region.

With respect to operation (a), it is believed the Examiner will agree that, with today's sophisticated technology regarding heat sensors and the geographical location of objects by means of satellites (e.g., as briefly reviewed in the above-identified Attachment prepared by the Inventor), it is possible to locate, rapidly and with a high degree of precision, the surface water temperature of large bodies of water, the air pressure thereover, and the velocity and direction of winds, such as to indicate the possible onset of a hurricane. It would, of course, be critical to identify the onset of a hurricane as early as possible, and its location as precisely as possible, since the amount of energy needed to inhibit or weaken the hurricane formation would greatly depend on such determinations.

With respect to operations (b) and (c), the specification describes specific manners of implementing the cooling operation by using nuclear-powered

submarines. Such submarines may be used to cool the surface water by pumping the cooler water, at the depth of the open water region, to the surface of the open water region. Since the water in depth is considerably cooler than the water at the surface, such pumping will inherently cool the surface water. In fact, this is the technique used in the method for weather modification described in Bronicki et al., U.S. Patent 4,470,544, cited by the Examiner. Since that patent is not concerned with inhibiting or weakening the formation of hurricanes, it does not include the step of detecting the onset of a hurricane; clearly, therefore, that patent is not relevant to the present invention except for showing that surface water can be cooled by pumping depth water to the surface, and for showing another utility. Using depth water for cooling surface water is also employed by Girden U.S. Patent 3,683,627 cited by the Examiner, for inhibiting hurricanes among other possible uses, but this is done in a completely different manner from the present invention utilizing sea vehicles for this purpose.

The specification in the present application not only describes the broad use of nuclear-powered submarines for cooling the surface water, but also describes three possible submarine arrangements that may be used. Thus, Fig. 1 shows a single submarine; Fig. 2 shows a plurality of submarines deployed horizontally over a large area of the open water region; and Fig. 3 shows a plurality of such submarines deployed vertically at different depths of the open water region. One of such configurations could be considered to be the "best mode" known to the Applicant, depending on how early the onset of a hurricane can be identified and located, and how much cooling may be required to weaken or inhibit the formation of the hurricane. Since nuclear submarines are presently available in relatively large numbers, are extremely mobile, and are capable of generating tremendous amounts of

energy for long periods of time, it would appear that the broad object of the present invention -- to inhibit, or at least weaken, hurricane formation -- could be implemented in this manner. At least there is no showing of any reason why such an implementation would not work.

On page 4 of the Official Action, the Examiner defines the standard for enablement as follows:

> "The standard for enablement is whether a person skilled in the art would have sufficient information from the application disclosure to make and use the claimed invention without undue experimentation."

The Examiner then sets forth seven reasons why, in his opinion, undue experimentation would be necessary in this case in order to use the disclosed process. Each of the seven reasons set forth by the Examiner is discussed below:

1. "The claimed invention is broad and sweeping in scope"

In this respect, it is to be pointed that Claim 1 defines a "method of inhibiting or weakening the formation of hurricanes". That is to say, the claim covers the possibility of <u>at least weakening</u> the hurricane. It is believed clear, and to be supported by the two patents cited above, the references cited in the Inventor's Attachment, and particularly by the "Controlling Hurricanes" article to be discussed below, that cooling of the surface water in accordance with the present invention will inherently have <u>some affect</u> in reducing the initial energy fed into the hurricane at its early stages, as well as reducing the new energy fed into the hurricane as it increases in intensity. It is reasonable to expect, therefore, that this will inherently reduce, <u>to some degree</u>, the infeed of new energy and thereby the intensity of the hurricane,

since, as pointed out in, e.g., References 1 and 3 in the Attachment by the Inventor, hurricanes tend to dissipate when moving over colder water

2. "The nature of the invention is that of a large-scale environmental change"

In this respect, we again refer to the above-quoted passage from the Encyclopedia Britannica, and point out that the present invention, like the ice-nuclei seeding technique referred to in that passage, does not represent a "brute force" approach for inhibiting or weakening hurricanes, but rather a somewhat elegant "spoiler" approach whereby a small input of energy upsets or "spoils" a natural instability and leads to large results. The operability of such an approach is further supported by the "Controlling Hurricanes" article as discussed below.

3. "The state of the prior art offers no reasonable background from which to judge the feasibility of the invention"

If there is no such prior art, this is because the problem of hurricanes, as devastating as they have been throughout history, has not yet been solved or even mitigated to any significant extent. However, the above discussion, the references cited in the Attachment prepared by the Inventor, Girden U.S. Patent 3,683,627 cited by the Examiner, and particularly the "Controlling Hurricanes" article discussed below, are believed sufficient to support a conclusion that the object -- to inhibit or at least weaken a hurricane formation -- is attainable by the present invention in the present state of the art. At least, there has been no showing or indication that the proposed method is inconsistent with any recognized physical principle or is otherwise incapable of being achieved by the present state of science and technology.

4. "The level of one of ordinary skill in this art is best characterized as that of a theoretical scientist dealing in probabilities and possibilities rather than that of an engineer dealing in practical applications of technology"

It is believed that not only the Applicant, but also the author of the attached "Controlling Hurricanes" article, would question the correctness of this statement. In Applicant's opinion, the theory on which the present invention is based is clearly consistent with recognized principle of physics, and therefore could be implemented by engineers dealing in practical applications of existing technology. It is believed that this is also clearly supported by the work and studies reported in the "Controlling Hurricanes" article discussed below.

5. "The outcome of the disclosed concept is entirely unpredictable"

Again it is to be emphasized that the invention purports to at least weaken the formation of a hurricane. It is believed that the work and studies reported in the attached "Controlling Hurricanes" article clearly support an expectation that the method could <u>at least weaken a hurricane to some extent</u>. It is submitted that this is all that is required under 35 USC 101.

6. "The application is devoid of working examples"

A demonstration of the invention, or providing working examples, would require facilities, funds and manpower far in excess of what is available to an individual inventor, such as the inventor in the present application. However, it is believed that the work and studies reported in the attached "Controlling Hurricanes" article provide such evidence and reasoning to permit one skilled in the art to expect that the method claimed could achieve the asserted useful result. Moreover, it is

believed that neither a demonstration nor working examples are required in this case, at least over and above those described in the attached "Controlling Hurricanes" article, in the absence of some showing or indication how the object of the invention (e.g., at least "weakening" the formation of a hurricane) is not attainable by the method described in the present application or is otherwise inconsistent with recognized principles of physics.

> 7. "The quantity of experimentation needed to use the invention based on the content of the disclosure can only be characterized as astronomical considering the lack of background information, past experimentation, and specific detail"

While the energy that would be required to suppress a raging hurricane would indeed be "astronomical", the energy required merely to "weaken" <u>to some extent</u> the hurricane formation would not be astronomical if this energy is applied immediately after the onset of a hurricane has been detected. As noted above, the proposed method is not a "brute force" approach, but rather an elegant "spoiler" approach (such as the ice-nuclei seeding technique referred to in the above quotation from the Encyclopedia Britannica as well as in the "Controlling Hurricanes" article) whereby a small input of energy upsets a natural instability and leads to large results. It is believed that the "Controlling Hurricanes" article, as well as the studies reported therein, provide the background and past experimentation information from which one skilled in the art could reasonably expect that a hurricane formation could <u>at least be weakened</u> in accordance with the described method.

In the absence of some showing or indication that the method proposed by the invention violates some recognized physical principle, or for some other reason is incapable of achieving the objects of the invention (to inhibit or to at least weaken hurricane formation), it is not believed essential under 35 USC 101 to require an

actual demonstration of the operability of the invention. Such a demonstration would require facilities, funds and manpower capable of being assembled only by an extremely large organization, and certainly not by an individual inventor.

The "Controlling Hurricanes" Article

The above article, which by coincidence appeared in the October 2004 issue of "Scientific American", under the title "Controlling Hurricanes" (pages 69 – 75) is believed to supply the "sufficient evidence and reasoning to permit a person of ordinary skill in the art to believe that the asserted utility or that the process disclosed could achieved the asserted useful results", as required by the Examiner in the Final Action of October 6, 2004 (pages 5 – 6).

First, it is to be noted that the author of this article, Ross N. Hoffman, is clearly an expert in this field, as evident from the brief biographic sketch of the author appearing at the bottom of page 72 of the article.

Secondly, it is to be noted that the studies reported and the opinions expressed in this article are based on computer-implemented models which (page 72, first full paragraph):

> "define the atmospheric state as a complete specification of the measurable physical variables, including pressure, temperature, relative humidity, and wind speed and direction."

Thirdly, it is to be noted that the studies reported in this article clearly indicate that the result of "weakening or inhibiting hurricanes" is achievable. See, for example, the following prominent heading appearing on page 75 of the article:

"Small changes can strongly influence a hurricane's potential path and power."

Also see the following statement appearing on page 71 of the article:

> "In the case of hurricanes, small changes in such features as the ocean's temperature, the location of the large-scale wind current (which drive the storms' movements), or even the shape of the rain clouds spinning around the eye can strongly influence a hurricane's potential path and power."

Page 74, middle column, described a hurricane simulation with respect to Hurricane Iniki, which prompted the following statement:

> "This run gave us confidence that we were on the right path to determining the changes needed to modify real hurricanes."

It is believed that the foregoing article, particularly when considered with the references cited in the Inventor's Attachment, provides sufficient evidence and reasoning to show that Applicant's method and apparatus, as described in the present application, are not based on mere speculation and conjecture, but rather are based on recognized physical principles which are capable of achieving the asserted useful result, namely the weakening or inhibiting of hurricanes, and therefore meet the requirement of "credible utility" under 35 USC 101.

CONCLUSIONS

In view of the foregoing, it is submitted: that language introduced in the previous amendment to the specification and claims objected to by the Examiner under 35 USC 132 and 35 USC 112, first paragraph, does not constitute "new matter" in violation of these sections of the code; that sufficient credible utilitiy of the described method and apparatus have been shown to meet the requirements of 35 USC 101; and that the description in the specification meets the "enabling" and "best mode" requirements under 35 USC 112, first paragraph. Accordingly, it is believed that the application should be allowed, and an early Notice of Allowance would therefore be appreciated.

Because the application is under Final, an early action is particularly solicited so as to avoid the necessity of filing an Appeal.

Respectfully submitted,

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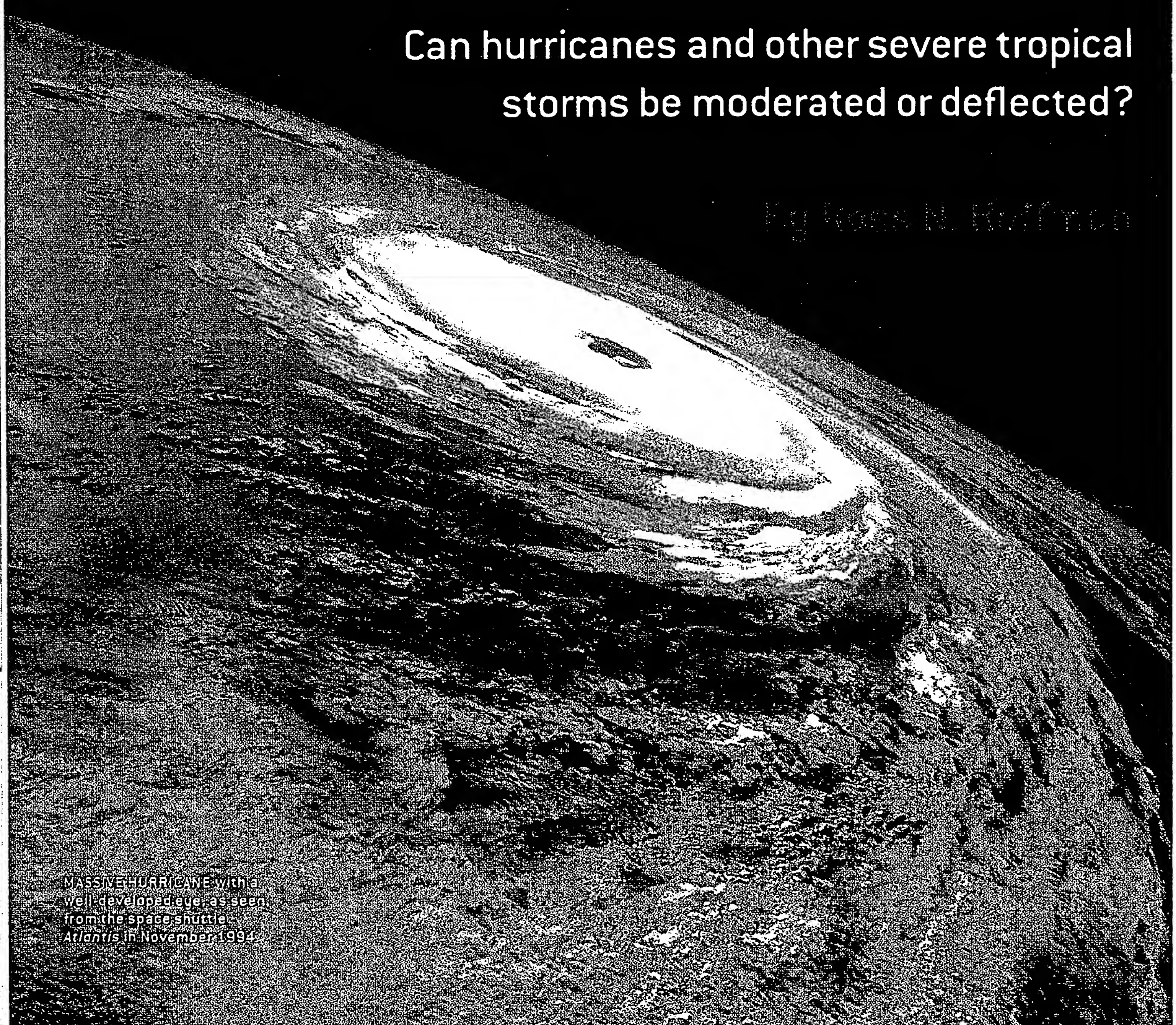
Registration No. 17,523
Attorney for Applicant

Date: December 8, 2004

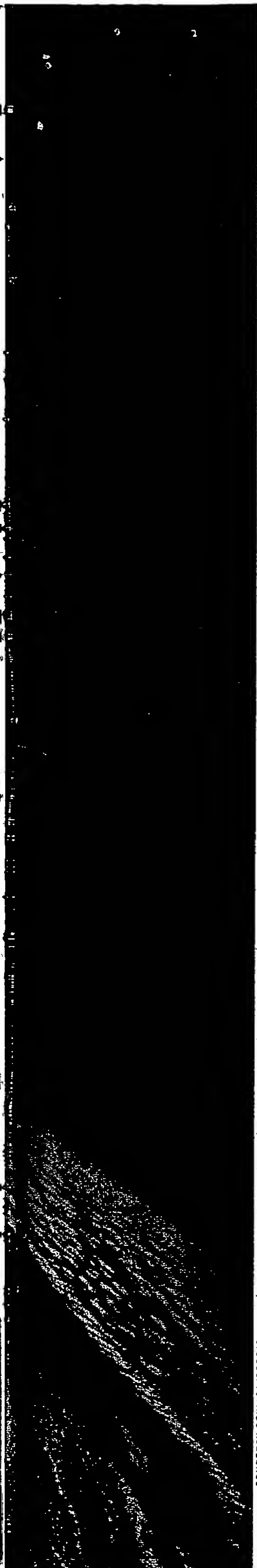
Controlling Hurricanes

Can hurricanes and other severe tropical storms be moderated or deflected?

By Ross N. Hoffman



MASSIVE HURRICANE with a well-developed eye, as seen from the space shuttle *Atlantis* in November 1994



COURTESY OF NASA/CORBIS

Every year **huge rotating storms** packing winds greater than 74 miles per hour sweep across tropical seas

and onto shorelines—often devastating large swaths of territory. When these roiling tempests—called hurricanes in the Atlantic and the eastern Pacific oceans, typhoons in the western Pacific and cyclones in the Indian Ocean—strike heavily populated areas, they can kill thousands and cause billions of dollars of property damage. And nothing, absolutely nothing, stands in their way.

But must these fearful forces of nature be forever beyond our control? My research colleagues and I think not. Our team is investigating how we might learn to nudge hurricanes onto more benign paths or otherwise defuse them. Although this bold goal probably lies decades in the future, we think our results show that it is not too early to study the possibilities.

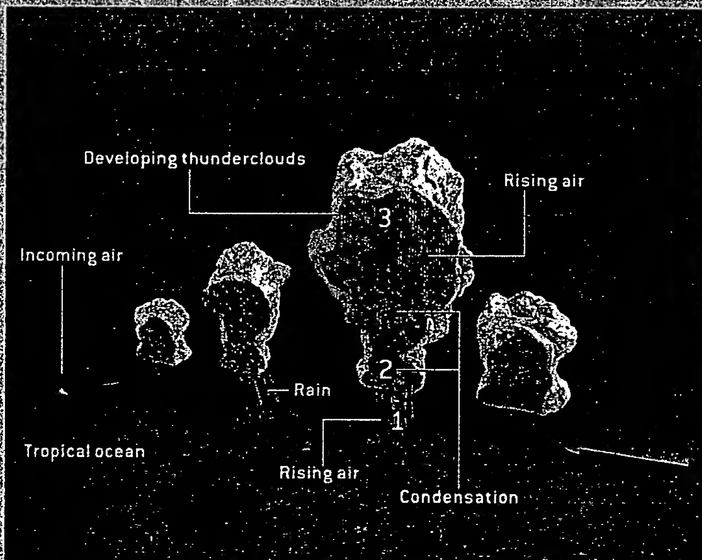
To even consider controlling hurricanes, researchers will need to be able to predict a storm's course extremely accurately, to identify the physical changes (such as alterations in air temperature) that would influence its behavior, and to find ways to effect those changes. This work is in its infancy, but successful computer simulations of hurricanes carried out during the past few years suggest that modification could one day be feasible. What is more, it turns out the very thing that makes forecasting any weather difficult—the atmosphere's extreme sensitivity to small stimuli—may well be the key to achieving the control we seek. Our first attempt at influencing the course of a simulated hurricane by making minor changes to the storm's initial state, for example, proved remarkably successful, and the subsequent results have continued to look favorable, too.

To see why hurricanes and other severe tropical storms may be susceptible to human intervention, one must understand their nature and origins [*see box on next two pages*]. Hurricanes grow as clusters of thunderstorms over the tropical oceans. Low-latitude seas continuously provide heat and moisture to the atmosphere, producing warm, humid air above the sea surface. When this air rises, the water vapor in it condenses to form clouds and precipitation. Condensation releases heat—the solar heat it took to evaporate the water at the ocean surface. This so-called latent heat of condensation makes the air more buoy-

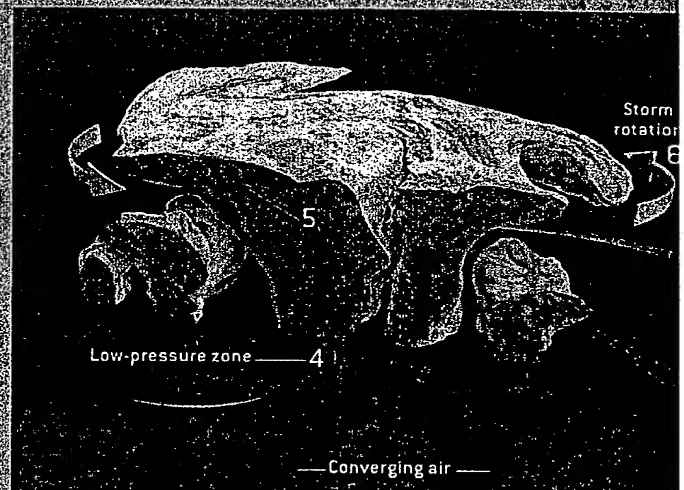
October 2004

ANATOMY OF A HURRICANE

Some scientists believe that they may be able to weaken or move hurricanes onto less dangerous tracks by altering the initial physical conditions (the air temperature or humidity, for example) in the center of the storm or even in the surrounding areas. To succeed, they need to make accurate and detailed forecasts of hurricanes. Here are the outlines of how these powerful storms arise.



Hurricanes start to form when tropical oceans release heat and water into the atmosphere, producing large amounts of warm, humid air above the surface (*1*). Warm air rises, and as it does so, the water vapor in it condenses to form clouds and rain (*2*). This condensation produces heat, causing air in the developing thunderclouds to climb still farther (*3*).



The release of heat above the tropical seas creates a surface low-pressure zone, where additional warm, moist air from the outer perimeter converges (*4*). This continuous movement into the burgeoning thunderstorm shifts h amounts of heat, air and water skyward (*5*). This upward transfer and rele of heat further enhance the convergence of surrounding air toward the growing storm center, which starts to circulate under the influence of the earth's rotation (*6*). The process continues apace, strengthening and organizing the storm.

ant, causing it to ascend still higher in a self-reinforcing feedback process. Eventually, the tropical depression begins to organize and strengthen, forming the familiar eye—the calm central hub around which a hurricane spins. On reaching land, the hurricane's sustaining source of warm water is cut off, which leads to the storm's rapid weakening.

Overview/*Taming Hurricanes*

- Meteorological researchers are simulating past hurricanes using sophisticated weather-forecasting models that closely reproduce the complex internal processes crucial to the development and evolution of severe tropical storms.
- The work confirms that these massive, chaotic systems are susceptible to minor changes in their initial conditions—for instance, the air temperature and humidity near the center of the storm and in the surrounding regions.
- Using complex mathematical optimization techniques, the researchers are learning what modifications to a hurricane could weaken its winds or divert it from populated areas.
- If these theoretical studies are ultimately successful, they should point the way toward practical methods for intervening in the life cycle of hurricanes to protect life and property.

Dreams of Control

BECAUSE A HURRICANE draws much of its energy from heat released when water vapor over the ocean condenses into clouds and rain, the first researchers to dream of taming these unruly giants focused on trying to alter the condensation process using cloud-seeding techniques—then the only practical way to try to affect weather. In the early 1960s a U.S. government-appointed scientific advisory panel named Project Stormfury performed a series of courageous (or perhaps foolhardy) experiments to determine whether that approach might work.

Project Stormfury aimed to slow the development of a hurricane by augmenting precipitation in the first rain band outside the eye wall—the ring of clouds and high winds that encircle the eye [see "Experiments in Hurricane Modification," by R. H. Simpson and Joanne S. Malkus; SCIENTIFIC AMERICAN, December 1964]. They attempted to accomplish this goal by seeding the clouds there with silver iodide particles dispersed by aircraft, which would serve as nuclei for the formation of ice from water vapor that had been supercooled after rising to the highest, coldest reaches of the storm. If all went as envisioned, the clouds would grow more quickly, consuming the supplies of warm, moist air near the ocean surface, thus replacing the old eye wall. This process

the storm intensifies, an eye—a calm, low-pressure hub—typically forms. The eye is encircled by a ring of clouds and high winds called the eye wall. The storm has become a hurricane. At the same time, the rising air, now ated and having lost much of its moisture, can rise no further, because the stratosphere acts like a lid above the hurricane. Some of this dry air falls into the eye (9) and between the cloud bands (10), while the remainder spirals away from the storm center and descends (11). Meanwhile large-scale air currents nearby steer the hurricane along its path.

would then expand the radius of the eye, lessening the hurricane's intensity in a manner akin to a spinning skater who extends her arms to slow down.

The Stormfury results were ambiguous at best. Meteorologists today do not expect this particular application of cloud seeding to be effective in hurricanes because, contrary to the early beliefs, the storms contain little supercooled water vapor.

Chaotic Weather

OUR CURRENT STUDIES grew out of an intuition I had 30 years ago when I was a graduate student learning about chaos theory. A chaotic system is one that appears to behave randomly but is, in fact, governed by rules. It is also highly sensitive to initial conditions, so that seemingly insignificant, arbitrary inputs can have profound effects that lead quickly to unpredictable consequences. In the case of hurricanes, small changes in such features as the ocean's temperature, the location of the large-scale wind currents (which drive the storms' movements), or even the shape of the rain clouds spinning around the eye can strongly influence a hurricane's potential path and power.

~~The atmosphere's~~ great sensitivity to tiny influences—and the rapid compounding of small errors in weather-forecasting models—is what makes long-range forecasting (more than five days in advance) so difficult. But this sensitivity also made me wonder whether slight, purposely applied inputs to a hurricane might generate powerful effects that could influence the storms, whether by steering them away from population centers or by reducing their wind speeds.

I was not able to pursue those ideas back then, but in the past decade computer simulation and remote-sensing technologies have advanced enough to renew my interest in large-scale weather control. With funding support from the NASA Institute for Advanced Concepts, my co-workers and I at Atmospheric and Environmental Research (AER), an R&D consulting firm, are employing detailed computer models of hurricanes to try to identify the kinds of actions that might eventually be attempted in the real world. In particular, we use weather-forecasting technology to simulate the behavior of past hurricanes and then test the effects of various interventions by observing changes in the modeled storms.

Modeling Chaos

EVEN TODAY'S BEST weather prediction computer models leave much to be desired when it comes to forecasting, but with effort they can be useful for modeling these storms. The models depend on numerical methods that simulate a storm's complex development process by computing the estimated atmospheric conditions in brief, successive time steps. Numerical weather prediction calculations are based on the assumption that within the atmosphere there can be no creation or destruction of mass, energy, momentum and moisture. In a fluid sys-

tem like a hurricane, these conserved quantities are carried along with the storm's flow. Near the boundaries or margins of the system, however, things get more complicated. At the sea surface, for example, our simulations account for the atmosphere gaining or losing the four basic conserved quantities.

Modelers define the atmospheric state as a complete specification of the measurable physical variables, including pressure, temperature, relative humidity, and wind speed and direction. These quantities correspond to the conserved physical properties on which the computer simulations are based. In most weather models these observable variables are defined on a three-dimensional grid representation of the atmosphere, so one can plot a map of each property for each elevation. Modelers call the collection of values of all the variables at all the grid points the model state.

To generate a forecast, a numerical weather prediction model repeatedly advances the model state from one instant through a small time step (a few seconds to a few minutes depending on the scales of motion resolved by the model). It calculates the effects during each time step of winds carrying along the various atmospheric properties and of the processes of evaporation, rainfall, surface friction, infrared cooling and solar heating that occur in the area of interest.

Unfortunately, meteorological forecasts are imperfect. In the first place, the beginning model state is always incomplete and inexact. Initial states for hurricanes are particularly difficult to define because direct observations are few and difficult to make. Yet we do know from satellite cloud images that hurricanes have complex and detailed structures. Although these cloud images are potentially useful, we need to know much more. Second, even with a perfect initial state, computer models of severe tropical storms are themselves prone to error. The atmosphere, for example, is modeled only at a grid of points. Features smaller than the grid length, the distance between two neighboring grid points, cannot be handled correctly. Without very high resolution, a hurricane's structure near the eye wall—its most important feature—is smoothed out and the details are unclear. In addition, the models, just like the atmosphere they simulate, behave in a chaotic fashion, and inaccuracies from both these error sources grow rapidly as the forecast computations proceed.

Despite its limitations, this technology is still valuable for our purposes. We have modified for our experiments a highly effective forecast initialization system called four-dimensional variational data assimilation (4DVAR). The fourth dimension to which the name refers is time. Researchers at the European Center for Medium-Range Weather Forecasts, one of the world's premier meteorological centers, use this sophisticated technique to predict the weather every day. To make best use of all the observations collected by satellites, ships, buoys and airborne sensors before the forecast begins, 4DVAR combines these measurements with an educated first guess of the initial atmospheric state—a process called data assimilation. This first guess is usually a six-hour forecast valid at the time of the original observations. Note that 4DVAR accounts for each observation just when it was taken rather than grouping them across a time interval of several hours. The result of merging the observational data and the first guess is then used to initiate the subsequent six-hour forecast.

In theory, data assimilation produces an optimal approximation of the weather in which the fit of the model's representation to the observations is balanced against its fit to the first guess. Although the statistical theory for this problem is clear, the assumptions and information needed for its proper application are only approximate. As a result, practical data assimilation is part art and part science.

Specifically, 4DVAR finds the atmospheric state that satisfies the model equations and that is also close to both the first guess and the real-world observations. It accomplishes this difficult task by back-adjusting the original model state at the start of the six-hour interval according to the difference between observations and model simulation made during that period. In particular, 4DVAR employs these differences to calculate the model's sensitivity—how small changes in each of the parameters would affect the degree to which the simulation fit the observations. This computation, using the so-called adjoint model, runs backward in time over the six-hour interval. An optimization program then chooses the best adjustments to make to the original model state to achieve a simulation that most closely matches the progress of the actual hurricane during the six-hour period.

Because this adjustment is made using an approximation of the model equations, the entire process—the simulation, the comparisons, the adjoint model and the optimization—must be repeated again and again to fine-tune the results. When the process is complete, the conditions of the simulation at the end of the

The altered version of Hurricane Iniki veered off, so that Kauai escaped the storm's most damaging winds.

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six-hour period then supplies the first guess for the next six-hour interval.

After simulating a hurricane that occurred in the past, we can then change one or more of its characteristics at any given time and examine the effects of these perturbations. It turns out that most such alterations simply die out. Only interventions with special characteristics—a particular pattern or structure that induces self-reinforcement—will develop sufficiently to have a major effect on a storm. To get an idea of what this means, think of a pair of tuning forks, one vibrating, the other stationary. If the forks are tuned to different frequencies, the second fork does not move, despite being struck repeatedly by sound waves emitted by the first. But if the devices share the same frequency, the second fork will respond in a resonant manner and vibrate sympathetically. In an analogous fashion, our challenge is to find just the right stimuli—changes to the hurricane—that will yield a robust response that leads to the desired results.

Calming the Tempest

TO EXPLORE WHETHER the sensitivity of the atmospheric system could be exploited to modify atmospheric phenomena as powerful as hurricanes, our research group at AER conducted computer simulation experiments for two hurricanes that occurred in 1992. When Hurricane Iniki passed over the Hawaiian island of Kauai in September of that year, several people died, property damage was enormous and entire forests were leveled. Hurricane Andrew, which struck Florida just south of Miami the month before, left the region devastated.

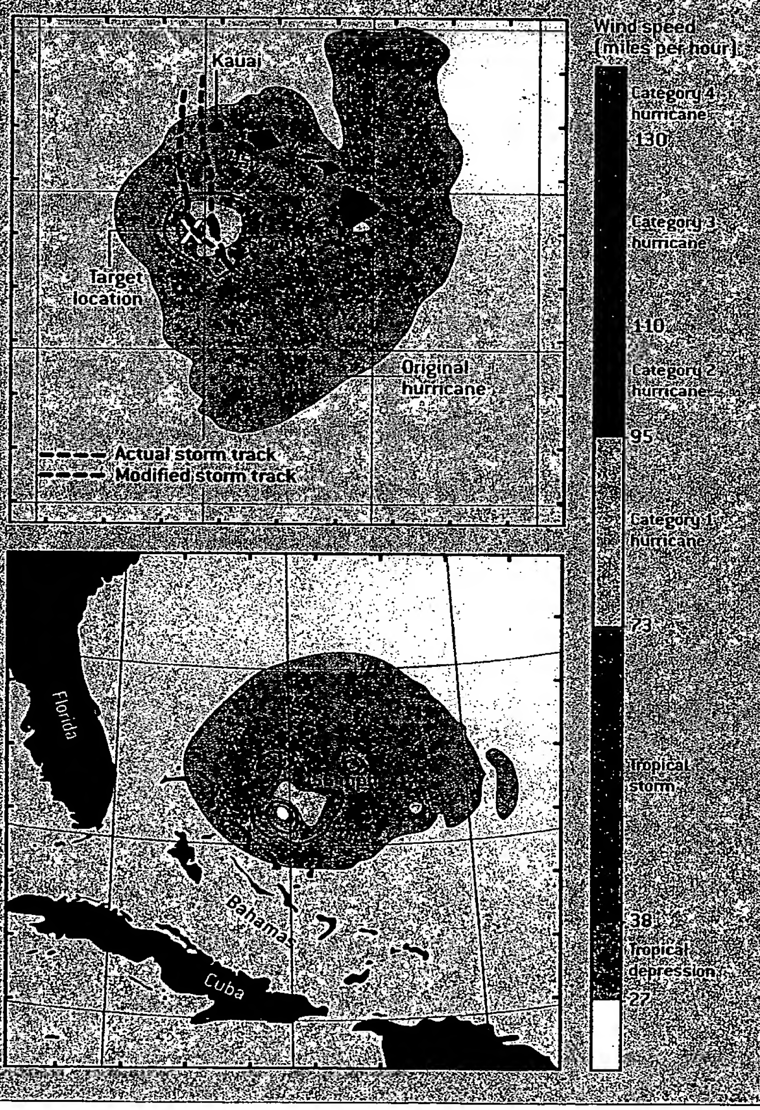
Surprisingly, given the imperfections of existing forecasting technologies, our first simulation experiment was an im-

CONTROL OF SIMULATED HURRICANES

Researchers are using computer models to simulate two destructive 1992 hurricanes, Iniki and Andrew. The colors represent wind-velocity categories, whereas black contour lines indicate gales of 56 miles per hour, generally the lowest wind speed that produces damage.

In the simulations of Iniki (*right*), the original track of the eye (*black dotted line*) takes the storm's high winds onto the Hawaiian island of Kauai. But when several of the model's initial conditions, including its temperature and humidity at various points, were altered slightly, the simulated storm track (*red dotted line*) veered to the west of Kauai, passing over a target location some 60 miles away. It then continued northward, moving farther west of the island.

The maps of the seas off Florida and the Bahamas below depict simulations of Andrew in its unaltered state (*left*) and in an artificially perturbed (*right*) form. Although damaging winds remain in the controlled case, maximum velocities have been reduced significantly, thus calming a Category 3 hurricane to a much milder Category 1 state.



mediate success. To alter the path of Iniki, we first chose where we wanted the storm to end up after six hours—about 60 miles west of the expected track. Then we used this target to create artificial observations and fed these into 4DVAR. We set the computer to calculate the smallest change to the initial set of the hurricane's key defining properties that would yield a track leading to the target location. In this early experiment we permitted any kind of possible artificial alteration to the storm system to take place.

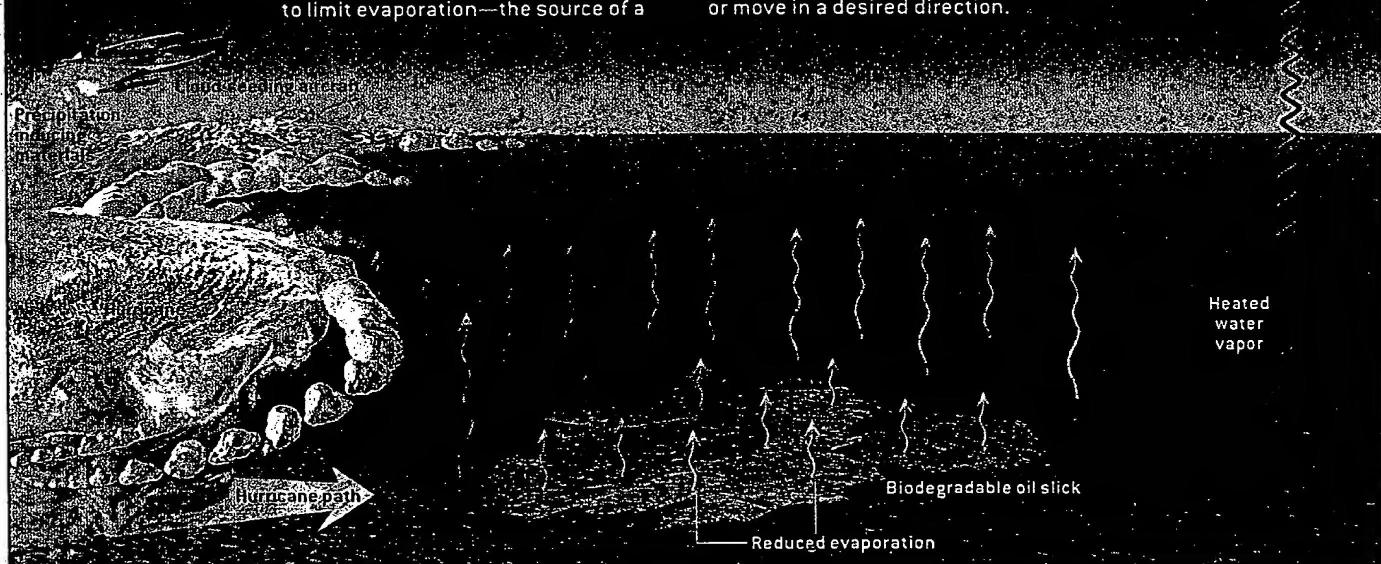
The most significant modifications proved to be in the starting temperatures and winds. Typical temperature adjustments across the grid were mere tenths of a degree, but the most notable change—an increase of nearly two degrees Celsius—occurred in the lowest model layer west of the storm center. The calculations yielded wind-speed alterations of two or three miles per hour. In a few locations, though, the velocities changed by as much as 20 mph because of minor redirections of the winds near the storm's center.

Although the original and altered versions of Hurricane Iniki looked nearly identical in structure, the changes in the key variables were large enough that the latter veered off to the west for the first six hours of the simulation and then traveled due north, so that Kauai escaped the storm's most damaging winds. The relatively small, artificial alterations to the storm's initial conditions had propagated through the complex set of nonlinear equations that simulated the storm to result in the desired relocation after six hours. This run gave us confidence that we were on the right path to determining the changes needed to modify real hurricanes. For the subsequent hurricane simulation trials, our team used higher grid resolutions to model the hurricane and set 4DVAR to the goal of minimizing property damage.

In one experiment using the modified code, we calculated the temperature increments needed to limit the surface wind damage caused by Hurricane Andrew as it hit the Florida coast. Our goal was to keep the initial temperature perturbation to a minimum (to make it as easy to accomplish as possible in real life) and to curtail the most destructive winds over the last two hours of the first six-hour interval. In this trial, 4DVAR determined that the best way to limit wind damage would be to make the greatest modifications to the beginning temperature near the storm's eye. Here the simulation produced changes as large as two or three degrees C at a few locations. Smaller temperature alterations (less than 0.5 degree C) extended out 500 to 600 miles from the eye. These perturbations feature a wavelike pattern of alternating rings of heating and cooling centered on the hurricane. Although only temperature had been changed at the start, all key variables were

HURRICANE INTERVENTION

Computer simulations of hurricanes indicate that changes in precipitation, evaporation and air temperature could alter a storm's path or weaken its winds. Intervention might take various forms: Carefully targeted aerial cloud seeding with silver iodide or other precipitation-inducing materials might serve to rob a hurricane's violent eye wall—the key feature of a severe tropical storm—of the water it needs to grow and intensify (*left*). Biodegradable oil could be distributed across the sea surface in the path of a hurricane to limit evaporation—the source of a storm's energy (*center*). Future earth-orbiting solar power stations, which could employ large mirrors to focus the sun's rays and panels of photovoltaic cells to harvest the energy for transfer down to the earth, might be used to beam microwaves tuned to be absorbed by water vapor molecules in the storm or in its surroundings (*right*). The microwaves would cause the water molecules to vibrate and heat the surrounding air, thus causing the hurricane to weaken or move in a desired direction.



soon affected. In the case of the original simulated hurricane, damaging winds (greater than about 56 mph) covered populated areas in South Florida by the end of six hours, but in the altered model run, they did not do so.

As a test of the robustness of these results, we applied the same perturbation to a more sophisticated, higher-resolution version of the model. We obtained very similar results, which show that our experiments are reasonably insensitive to our particular choice of model configuration. After six hours, however, damaging winds reappeared in the altered simulation, so additional interventions would have been required to keep South Florida safe. Indeed, it looks as if a series of planned disturbances would be required to control a hurricane for any length of time.

Who Can Stop the Rain?

IF IT IS TRUE, as our results suggest, that small changes in the temperature in and around a hurricane can shift its path in a predictable direction or slow its winds, the question becomes, How can such perturbations be achieved? No one, of course, can alter the temperature throughout something as large as a hurricane instantaneously. It might be possible, however, to heat the air around a hurricane and thus adjust the temperature over time.

Our team plans to conduct experiments in which we will calculate the precise pattern and strength of atmospheric heating needed to moderate hurricane intensity or alter its track. Undoubtedly, the energy required to do so would be huge, but an array of earth-orbiting solar power stations could eventually be used to supply sufficient energy. These power-generating satellites might use giant mirrors to focus sunlight on solar cells and then beam the collected energy down to microwave receivers on the ground. Current designs for space solar power stations would radiate microwaves at frequencies that pass through the atmosphere without heating it, so as to not waste energy. For weather control, however, tuning the microwave downlink to frequencies better absorbed by water vapor could heat different levels in the atmosphere as desired. Because raindrops strongly absorb microwaves, parts of the hurricane inside and beneath rain clouds would be shielded and so could not be heated in this way.

In our previous experiments, 4DVAR determined large temperature changes just where microwave heating could not work, so we ran an experiment in which we forced the temperature in the center of the hurricane to remain constant during our calculation of the optimal perturbations. The final results resembled those of the original, but to compensate for making no initial temperature changes in the storm center the remaining temperature changes had to be larger. Notably, temperature changes developed rapidly near the storm center during the simulation.

Another potential method to modify severe tropical storms would be to directly limit the availability of energy by coating the ocean surface with a thin film of a biodegradable oil that slows evaporation. Hurricanes might also be influenced by introducing gradual modifications days in advance of their approach and thousands of miles away from their eventual targets. By altering air pressure, these efforts might stimulate changes in the large-scale wind patterns at the jet-stream level, which can have major effects on a hurricane's intensity and track. Further, it is possible that relatively minor alterations to our normal activities—such as directing aircraft flight plans to precisely position contrails and thus increase cloud cover or varying crop irrigation practices to enhance or decrease evaporation—might generate the appropriate starting alterations.

What if Control Works?

IF METEOROLOGICAL control does turn out to work at some point in the future, it would raise serious political problems. What if intervention causes a hurricane to damage another country's territory? And, although the use of weather modification as a weapon was banned by a United Nations Convention in the late 1970s, some countries might be tempted.

Before those kinds of concerns arise, however, our methods would need to be proved on atmospheric phenomena other than hurricanes. In fact, we believe our techniques should first be tried out in an effort to enhance rainfall. This approach could then serve as a test bed for our concepts in a relatively small region that could be instrumented densely with sensors. For such reduced size scales, perturbations could be introduced from aircraft or from the ground. If our understanding of cloud physics, computer simulation of clouds and data assimilation techniques advance as quickly as we hope, these modest trials could be instituted in perhaps 10 to 20 years. With success there, larger-scale weather control using space-based heating may become a reasonable goal that nations around the globe could agree to pursue. SA

Small changes can strongly influence a hurricane's potential path and power.

MORE TO EXPLORE

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Ross N. Hoffman's technical presentations on weather modification can be found at www.niac.usra.edu/studies/